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Now to apply this (in a few words) to the Trumpet, where the Notes are produced only by the different force of the breath; it is reasonable to imagine that the strongest blast raises the sound by breaking the Air within the Tube into the shortest vibrations, but that no Musical sound will arise unless they are suited to some aliquot part, and so by reduplication exactly measure out the whole length of the Instrument, as in Fig. C, for otherwise a remainder will cause the same inconvenience in this case, as in Fig. D. To which if we add that a Pipe, being shortened according to the Proportions we even now discours'd of in a String, raises the sound in the same degrees, it renders the case of the Trumpet just the same with the Monochord.

For a Corollary to this Discourse, we may observe that the distances of the Trumpet Notes ascending, continually decreased in proportion of $\frac{1}{2} \frac{1}{2} \frac{1}{3} \frac{1}{4} \frac{1}{5}$ in *infinitum*, For,

The { second } Note in the { first } by { $\frac{1}{2}$ } of the String,
 { third } Table, differs { second } by { $\frac{1}{3}$ } &c.
 { fourth } from the { third } by { $\frac{1}{4}$ }

An Account of the cause of the Change of the Variation of the Magnetical Needle; with an Hypothesis of the Structure of the Internal parts of the Earth : as it was proposed to the Royal Society in one of their late Meetings. By Edm. Halley.

Some years since I published in these Transactions, (Numb. 148,) a Theory of the Variation of the Magnetical Compass, wherein having collected as many Observations as at that time I could procure, and having

carefully compared them together, I came at length to this general conclusion, *That the Globe of the Earth might be supposed to be one great Magnet, having four Magnetical Poles or Points of Attraction, near each Pole of the Equator two: and that in those parts of the World which lie near adjacent to any one of those Magnetical Poles, the Needle is chiefly governed thereby; the nearest Pole being alwaies predominant over the more remote.* And I there have endeavoured to state and limit the present position of those Poles in the Surface of our Globe, which the Reader pleasing to consult will save us the pains of repeating. But after all though that Discourse was favourably received both at home and abroad, as seeming to render a tollerable account of the observed Variations, yet I found two difficulties not easie to surmount, the one was that no Magnet I had ever seen or heard of, had more than two opposite Poles; whereas the Earth had visibly four, and perhaps more. And secondly, it was plain that those Poles were not, at least all of them, fixt in the Earth, but shifted from place to place, as appeared by the great changes in the Needles direction within this last Century of years, not only at *London* (where this great Discovery was first made,) but almost all over the Globe of Earth; whereas it is not known or observed that the Poles of a Load-Stone ever shifted their place in the Stone, nor (considering the compact hardness of that substance) can it easily be supposed: Though the Matter of Fact be too notorious and universal, not to be accounted for.

These difficulties had wholly made me despond, and I had long since given over an inquiry I had so little hopes of; when in accidental discourse, and least expecting it, I stumbled on the following Hypothesis; in delivering whereof, if I shall seem to advance any thing that looks like Extravagant or Romantick, the Reader is desired to suspend his censure, till he have considered

considered the force and number of the many Arguments which concur to make good so new and so bold a Supposition.

Though it be sufficiently known and allowed that the Needles Variation changes, it will be necessary however to give a few instances, whereby it may appear that this change is gradual and universal, and the effect of a great and permanent motion. For which take the following Examples.

At *London* in the year 1580, the Variation was observed by Mr. *Burrows* to be $11^{\circ} 15'$ East. In *Anno* 1612, the same was found by Mr. *Gunter* to be but $6^{\circ} 0'$ East. In the year 1634, Mr. *Gellibrand* found it $4^{\circ} 5'$ East. In 1657, Mr. *Bond* observed that there was no Variation at *London*. *Anno* 1672, my self observed it $2^{\circ} 30'$ to the West; and this present year 1692. I again found it $6^{\circ} 00'$ West. So that in 112 years the direction of the Needle has changed no less than 17 degrees.

At *Paris*, *Orontius Finaus* about the year 1550, did account it about 8 or 9 degrees East Variation. *Anno* 1640, it was found 3 degrees East. *Anno* 1666, there was no Variation there, and *Anno* 1681, I found it to be $2^{\circ} 30'$ to the West.

At *Cap d' Agulhas*, the most southerly Promontory of *Africa*. about the year 1600, the Needle pointed due North and South without Variation, whence the *Portuguese* gave it its name. *Anno* 1622, there was 2 degrees West Variation. *Anno* 1675, it was $8^{\circ} 00'$ West; and this year 1691. it was curiously observed not less than 11 degrees West.

At *St. Helena*, about the year 1600, the Needle declined 8 degrees to the East. *Anno* 1623, it was but $6^{\circ} 00'$ East. *Anno* 1677, when I was there, I observed it accurately on shore to be *o d.* $40'$ East; and now this year it was found about 1 *d.* to the Westward of the North.

At *Cape Comorine* in *India*, in the Year 1620, there was $14^{\circ} 20'$ West Variation; in the Year 1680, there was $8^{\circ} 48'$, but now lately in the Year 1688, it was no more than $7^{\circ} 30'$, so that here the Needle has returned to the East about seven degrees in seventy Years.

In all the other Examples the Needle has gradually moved towards the West, and the places are too far asunder to be influenced by the removal of any Magnetical matter, which may by accident be transplaced within the Bowels or on the Surface of the Earth. If more Examples are desired, the Reader may be furnished with them in the *Portuguese Routier* of *Aleixo de Motta* (written about the year 1600,) and in the Voyage of *Beaulieu*, both published in Mr. *Thevenot's* first Collection of curious Voyages, printed at *Paris*, anno 1663. which he is to compare with the Journals of our late *East India* Voyagers, and I am assured that it will be thereby evident, that the Direction of the Needle is in no place fixt and constant, tho' in some it change faster than in others. And where for a long time it has continued as it were unaltered, it is there to be understood that the Needle has its greatest deflection, and is become Stationary in order to return, like the Sun in the Tropick. This at present is in the *Indian* Sea, about the Island *Mauritius*, where is the highest West Variation, and in a Tract tending from thence into the N. N. W. towards the *Red Sea* and *Egypt*. And in all Places to the Westward of this Tract, all over *Africa* and the Seas adjoining, the West Variation will be found to have encreased; and to the Eastwards thereof, as in the example of *Cape Comorine*, to have decreased, *viz.* all over the *East-Indies* and the Islands near it.

After the like manner in that Space of East Variation which, beginning near *St. Helena*, is found all over the South

South *America*, and which at present is highest about the Mouth of *Rio de la Plata*, it has been observed that in the Eastern parts thereof, the Variation of the Needle gradually decreases; but whether on the contrary it increases in those places which lie more Westerly than that tract wherein the highest East Variation is found; or how it may be in the vast *Pacifick Sea*, we have not experience enough to ascertain, only we may by Analogy infer, that both the East and West Variations therein do gradually increase and decrease after the same Rule.

These *Phænomena* being well understood and duly considered do sufficiently evince, That the whole magnetical System is by one or perhaps more Motions translated, whether Eastwards or Westwards I shall anon discuss; that this moving thing is very great, as extending its effects from Pole to Pole; and that the Motion thereof is not *per saltum*, but a gradual and regular Motion.

Now considering the structure of our *Terraqueous* Globe, it cannot be well supposed that a very great part thereof can move within it, without notably changing its Centre of Gravity and the Equilibre of its parts, which would produce very wonderful Effects in changing the Axis of Diurnal Rotation, and occasion strange alteration in the Sea's Surface, by Inundations and Recesses thereof, such as History never yet mentioned. Besides, the solid parts of the Earth are not to be granted permeable by any other than fluid Substances, of which we know none that are any ways Magnetical. So that the only way to render this Motion intelligible and possible, is, to suppose it to turn about the Centre of the Globe, having its Centre of Gravity fixt and immovable in the same common Centre of the Earth: And there is yet required that this moving internal Substance be loose and detached from the external parts of the Earth, whereon we live; for otherwise were it affix'd thereto

thereto, the whole must necessarily move together.

So then the External Parts of the Globe may well be reckoned as the Shell, and the Internal as a *Nucleus* or inner Globe included within ours, with a fluid medium between. Which having the same common Centre and Axis of diurnal Rotation, may turn about with our Earth each 24 hours; only this outer Sphere having its turbinating Motion some small matter either swifter or slower than the internal Ball. And a very minute difference in length of time, by many repetitions becoming sensible; the Internal parts will by degrees recede from the External, and not keeping pace with one another will appear gradually to move either Eastwards or Westwards by the difference of their Motions.

Now supposing such an Internal Sphere having such a Motion, we shall solve the two great difficulties we encountred in my former Hypothesis. For if this exterior Shell of Earth be a Magnet having its Poles at a distance from the Poles of Diurnal Rotation; and if the Internal *Nucleus* be likewise a Magnet, having its Poles in two other places distant also from the Axis; and these latter by a gradual and slow Motion change their place in respect of the External; we may then give a reasonable account of the four Magnetical Poles I presume to have demonstrated in No. 148. of these Transactions; as likewise of the changes of the Needles Variations, which till now hath been unattempted.

The Period of this Motion being wonderful great, and there being hardly an hundred Years since these Variations have been duly observed, it will be very hard to bring this Hypothesis to a Calculus, especially since, tho' the Variations do increase and decrease regularly in the same place, yet in differing places, at no great distance, there are found such casual Changes thereof

thereof as can no ways be accounted for by a regular Hypothesis: as depending upon the unequal and irregular distribution of the Magnetical matter within the substance of the External shell or coat of the Earth, which deflect the Needle from the position it would acquire from the effect of the general Magnetism of the whole. Of this the Variations at *London* and *Paris* give a notable instance, for the Needle has been constantly about 1° more Easterly at *Paris* than at *London*; tho' it be certain that according to the general effect the difference ought to be the contrary way. Notwithstanding which the Variations in both places do change alike.

Hence, and from some other of like nature, I conclude, That the two Poles of the external Globe are fixt in the Earth, and that if the Needle were wholly governed by them, the Variations thereof would be always the same, with some little Irregularities upon the account I but just now mentioned: But the internal Sphere having such a gradual translation of its Poles, does influence the Needle and direct it variously according to the result of the attractive or directive power of each Pole; and consequently there must be a period of the Revolution of this internal Ball, after which the Variations will return again as before. But if it shall in future ages be observed otherwise we must then conclude that there are more of these Internal Spheres, and more Magnetical Poles than Four, which at present we have not a sufficient number of Observations to determine, and particularly in that vast *Mar del Zur*, which occupies so great a part of the whole Surface of the Earth.

If then two of the Poles be fixt and two moveable, it remains to ascertain which they are that keep their place: and tho' I could wish we had the experience of another Century of years to found our Conclusions upon, yet I think we may safely determine, *That our European*

European North Pole (which in No. 148. I supposed near the Meridian of the Lands End of *England*, and about seven degrees therefrom) is that that is moveable of the two Northern Poles, and that that has chiefly influenced the Variations in these parts of the World : For in *Hudson's Bay*, which is under the Direction of the *American Pole*, the change is not observed to be near so fast as in these parts of *Europe*, tho' that Pole be much farther removed from the Axis.

As to the *South Poles*, I take the *Asian Pole*, which I place about the Meridian of the Island *Celebes* to be the fixt, and consequently the *American Pole* to move ; from the like observation of the slow decrease of the Variation on the Coast of *Java*, and near the Meridian of the *Asian Pole* ; tho' I must confess to have no account of the effects of the other beyond *Magellan's Streights*.

If this be allowed me, 'tis plain that the fixt Poles are the Poles of this External Shell or *Cortex* of the *Earth*, and the other two the Poles of a Magnetical *Nucleus* included and moveable within the other. It likewise follows, that this Motion is Westwards, and by consequence that the aforesaid *Nucleus* has not precisely attained the same degree of Velocity with the exterior parts in their Diurnal Revolution : but so very nearly equals it, that in 365 Revolves the difference is scarce sensible. This I conceive to arise from the Impulse whereby this diurnal Motion was impress'd on the *Earth*, being given to the external parts, and from thence in time communicated to the internal ; but not so as perfectly to equal the Velocity of the first Motion impress'd on, and still conserved by the superficial parts of the *Globe*.

As to the Quantity of Motion it is almost impossible to define it, both from the Nature of this kind of Observation, which cannot be very accurately performed

formed, as also from the small time these Variations have been observed, and their change discovered. It appears by all Circumstances, that its period is of many Centuries of Years, and as far as may be collected from the Change of the Place, where there was no Variation by reason of the Equilibre of the two Southern Magnetical Poles, *viz.* from *Cape d' Agulhas* to the Meridian of *St. Helena* (which is about 23^{rd} in about 90 years) and of the place where the Westerly Variation is in its *ἀκμὴ* or greatest Deflection, being about half so much, *viz.* from the Isle of *Diego Riox* to the South West parts of *Madagascar*. We may with some Reason conjecture, that the *American* Pole has moved Westwards 46 degrees in that time, and that the whole Period thereof is performed in 700 Years, or thereabouts; so that the nice Determination of this and of several other particulars in the Magnetick System is reserved for remote Posterity; all that we can hope to do is to leave behind us Observations that may be confided in, and to propose Hypotheses which after Ages may examine, amend or refute. Only here I must take leave to recommend to all Masters of Ships and all others, Lovers of natural Truths, that they use their utmost Diligence to make, or procure to be made, Observations of these Variations in all parts of the World, as well in the North as South Latitude (after the laudable custom of our *East-India* Commanders) and that they please to communicate them to the *Royal Society*, in order to leave as compleat a History as may be to those that are hereafter to compare all together, and to compleat and perfect this abstruse Theory.

And by the way it will not be amiss to amend a received Error in the Practice of observing the Variation, which is, to take it by the Amplitude of the Rising and Setting Sun, when his Centre appears in the visible Horizon; whereas he ought to be observed when his under

Limb is still above the Horizon about $\frac{2}{3}$ of his Diameter, or 20 Minutes, upon the score of the Refraction, and the height of the Eye of the Observer above the Surface of the Sea: Or else they are to work the Amplitudes as they do the Azimuth, reckoning the Sun's distance from the Zenith $90^{\circ} 36'$. This, tho' it be of little consequence near the Equinoctial, will make a great error in high Latitudes, where the Sun rises and sets obliquely.

But to return to our Hypothesis, in order to explain the change of the Variations, we have adventured to make the Earth hollow and to place another Globe within it: and I doubt not but this will find Opposers enough. I know 'twill be objected, That there is no Instance in Nature of the like thing; That if there was such a middle Globe it would not keep its place in the Centre, but be apt to deviate therefrom, and might possibly chock against the concave Shell, to the ruine or at least endammaging thereof; That the Water of the Sea would perpetually leak through, unless we suppose the Cavity full of Water; That were it possible yet it does not appear of what use such an inward Sphere can be of, being shut up in eternal Darknels, and therefore unfit for the Production of Animals or Plants; with many more Objections, according to the Fate of all such new Propositions.

To these, and all others that I can foresee, I briefly answer, That the Ring environing the Globe of *Saturn* is a notable Instance of this kind, as having the same common Centre, and moving along with the Planet, without sensibly approaching him on one side more than the other. And if this Ring were turned on one of its Diameters, it would then describe such a concave Sphere as I suppose our External one to be. And since the Ring in any position given, would in the same manner keep the Centre of *Saturn* in its own, it follows that such a

concave

concave Sphere may move with another included in it, having the same common Centre. Nor can it well be supposed otherwise, considering the Nature of Gravity, for should these Globes be adjusted once to the same common Centre, the Gravity of the parts of the Concave would press equally towards the Centre of the inner Ball, which Equality must necessarily continue till some external force disturb it, which is not easie to imagine in our case. This perhaps I might more intelligibly express, by saying that the inner Globe being posited in the Centre of the exterior, must necessarily ascend which way soever it move; that is, it must overcome the force of Gravity pressing towards the common Centre, by an impulse it must receive from some outward Agent: but all outward efforts being sufficiently fenced against by the Shell that surrounds it, it follows, that this *Nucleus* being once fixt in the common Centre, must always there remain.

As to the leaking of the Water through this Shell, when once a passage shall be found for it to run through, I must confess it is an Objection seemingly of weight; but when we consider how tightly great Beds of Chalk or Clay, and much more Stone do hold water, and even Caves arch'd with Sand; no Man can doubt but the Wisdom of the Creator has provided for the Macrocosm by many more ways than I can either imagine or express, especially since we see the admirable and innumerable Contrivances wherewith each worthless Individual is furnisht both to defend it self and propagate its Species. What Curiosity in the Structure, what Accuracy in the Mixture and Composition of the parts ought not we to expect in the Fabrick of this Globe, made to be the lasting Habitation of so many various Species of Animals, in each of which there want not many Instances that manifest the boundless Power and Goodness of their Divine Author; and can

we then think it a hard supposition that the Internal parts of this Bubble of Earth should be replete with such Saline and Vitriolick Particles as may contribute to petrification, and dispose the transuding Water to shoot and coagulate into Stone, so as continually to fortifie, and if need were to consolidate any breach or flaw in the Concave Surface of the Shell.

And this perhaps may not without reason be supposed to be the final Cause of the admixture of the Magnetical Matter in the Mass of the Terrestrial parts of our Globe, viz. To make good and maintain the Concave Arch of this Shell: for by what the excellent Mr. *Newton* has shewn in his *Principia Philosophiæ*, it will follow that according to the general Principle of Gravity, visible throughout the whole Universe, all those Particles that by length of time or otherwise shall molder away or become loose on the Concave Surface of the External Sphere, would fall in, and with great force descend on the Internal, unless those Particles were of another sort of Matter capable by their stronger tendency to each other, to suspend the force of Gravity; but we know no other substances capable of supporting each other by their mutual Attraction but the Magnetical, and these we see miraculously to perform that Office, even where the power of Gravity has its full effect, much more within the Globe where it is weaker. Why then may we not suppose these said Arches to be lined throughout with a Magnetical Matter, or rather to be one great Concave Magnet, whose two Poles are the Poles we have before observed to be fixt in the Surface of our Globe.

Another Argument favouring this Hypothesis is drawn from a Proposition of the same Mr. *Newton*, where he determines the force wherewith the *Moon* moves the *Sea* in producing the *Tides*: his words are, *Densitas Luna est ad densitatem Terræ ut 680 ad 387 seu 9 ad 5 quàmproxime. Est igitur corpus Luna densius ac magis terrestre*
quàm

quam Terra nostra, p. 466. Now if the Moon be more solid than the Earth as 9 to 5, why may we not reasonably suppose the Moon, being a small Body and a Secondary Planet, to be solid Earth, Water, and Stone, and this Globe to consist of the same Materials, only four ninths thereof to be Cavity, within and between the internal Spheres: which I would render not improbable.

To those that shall enquire of what use these included Globes can be, it must be allowed, that they can be of very little service to the Inhabitants of this outward World, nor can the Sun be serviceable to them, either with his Light or Heat. But since it is now taken for granted that the Earth is one of the Planets, and they all are with reason supposed Habitable, though we are not able to define by what sort of Animals; and since we see all the parts of the Creation abound with Animate Beings, as the Air with Birds and Flies, the Water with the numerous varieties of Fish, and the very Earth with Reptiles of so many sorts; all whose ways of living would be to us incredible did not daily Experience teach us. Why then should we think it strange that the prodigious Mass of Matter, whereof this Globe does consist, should be capable of some other improvement than barely to serve to support its Surface? Why may not we rather suppose that the exceeding small quantity of solid Matter in respect of the fluid Ether, is so disposed by the Almighty Wisdom as to yield as great a Surface for the use of living Creatures as can consist with the conveniency and security of the whole. We our selves, in Cities where we are pressed for room, commonly build many Stories one over the other, and thereby accommodate a much greater multitude of Inhabitants.

But still it will be said that without Light there can be no living, and therefore all this *apparatus* of our inward Globes must be useless: to this I answer that there are many ways of producing Light which we are wholly ignorant

ignorant of; the Medium it self may be always luminous after the manner of our *Ignes fatui*. The Concave Arches may in several places shine with such a substance as invests the Surface of the Sun; nor can we, without a boldness unbecoming a Philosopher, adventure to assert the impossibility of peculiar Luminaries below, of which we have no sort of *Idea*. I am sure the Poets *Virgil* and *Claudian* have gone before me in this Thought, inlightning their *Elysian Fields* with Sun and Stars proper to those infernal, or rather internal, Regions. Vir. *Æneid.* 6.

*Largior hic campos æther & lumine vestit
Purpureo; Solemque suum sua Sidera norunt.*

And *Claudian* lib. 2. *De Raptu Proserpinæ.*

*Amissum ne crede diem, sunt altera nobis
Sidera, sunt orbes alii, lumenque videbis
Furius, Elysiumque magis mirabere Solem:*

And though this be not to be esteemed as an Argument, yet I may take the liberty I see others do, to quote the Poets when it makes for my purpose.

Lastly, To explain yet farther what I mean, I have adventured to adjoyn the following Scheme, wherein the Earth is represented by the outward Circle, and the three inward Circles are made nearly proportionable to the Magnitudes of the Planets *Venus*, *Mars* and *Mercury*, all which may be included within this Globe of Earth, and all the Arches more than sufficiently strong to bear their weight. The Concave of each Arch, which is shaded differently from the rest, I suppose to be made up of Magnetical Matter; and the whole to turn about the same common Axis *p. p.* only with this difference, that the Outer Sphere still moves somewhat faster than
the

the Inner. Thus the Diameter of the Earth being about eight thousand *Engliſh* Miles, I allow five hundred Miles for the thickneſs of its Shell, and another ſpace of five hundred Miles for a Medium between, capable of an immense Atmosphere for the Uſe of the Globe of *Venus*: *Venus* again I give a Shell of the ſame thickneſs, and leave as great a ſpace between her Concave and *Mars*; ſo likewiſe from *Mars* to *Mercury*, which latter Ball we will ſuppoſe ſolid, and about two thouſand Miles Diameter. Thus I have ſhewed a poſſibility of a much more ample Creation, than has hitherto been imagined; and if this ſeem ſtrange to thoſe that are unacquainted with the Magnetical System, it is hoped that all ſuch will endeavour firſt to inform themſelves of the Matter of Fact and then try if they can find out a more ſimple Hypotheſis, at leaſt a leſs abſurd, even in their own Opinions. And whereas I have adventured to make theſe Subterraneous Orbs capable of being inhabited, 'twas done deſignedly for the ſake of thoſe who will be apt to ask *cui bono*, and with whom Arguments drawn from *Final Cauſes* prevail much. If this ſhort Eſſay ſhall find a kind acceptance, I ſhall be encouraged to enquire farther, and to poliſh this rough Draft of a Notion till hitherto not ſo much as ſtarted in the World, and of which we could have no Intimation from any other of the *Phænomena* of Nature.

Since this was written, a Diſcovery I have made in the Celeftial Motions, ſeems to render a farther account of the Uſe of the Cavity of the Earth, *viz.* To diminith the Specifick Gravity thereof in reſpect of the Moon: for I think I can demonſtrate that the Oppoſition of the Ether to the Motions of the Planets in long time becomes ſenſible: and conſequently the greater Body muſt receive a leſs Oppoſition than the ſmaller, unleſs the Specifick Gravity of the ſmaller do proportionably exceed that of the greater, in which caſe only they can

can move together ; so that the Cavity I assign in the Earth, may well serve to adjust its weight to that of the Moon. For otherwise the Earth would leave the Moon behind it, and she become another Primary Planet. But this I design to explain by a Discourse apart more at large.

F I N I S.
